

IDENTIFYING PROCESSING DEFICITS IN LEARNING-
DISABLED CHILDREN USING REACTION-TIME METHODOLOGY

By

STEVEN ROBERT SHAW

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This work is dedicated to the memory of Dr. Robert Jester. His support, expertise, and kindness will not be forgotten.

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Steven Robert Shaw

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Learning-disabled (LD) children are defined as those who have received adequate instruction, do not have significantly below average intelligence as measured by psychometric intelligence tests, and have no emotional factors impeding learning, yet who have failed to learn. By definition, learning disabilities are caused by elementary cognitive processing deficits. However, psychometric, neuropsychological, and behavioral instruments have yet to shed light on the nature of such processing deficits and learning disabilities. Measuring the speed of information processing using the most elementary cognitive tasks minimizes the effects of previous learning and problem solving strategies, and, consequently, may provide important insight into the nature of processing deficits in LD

children. Ninety-six males between the ages of 12 and 14 years were administered a battery of five reaction-time (RT) tasks. The subjects comprised three groups of 32, matched for age and intelligence: Group 1 consisted of reading disabled only children, Group 2 consisted of mathematics disabled only children, and Group 3 consisted of non-learning disabled children. Results indicate that variables derived from RT tasks (mean reaction time, intraindividual variability, and response errors) correctly classified subjects into groups with 89% accuracy. Groups accounted for 83% of the variance among variables. The two LD groups were slower on most tasks than the non-LD group. However, there was a subset of the LD-Reading group that was significantly faster than the other groups on the simplest RT tasks. The performance of this subset does not fit any known theory of learning disabilities. It is concluded that LD children have difficulty in learning because of slower and more variable processing of information than non-LD children.

CHAPTER 1 INTRODUCTION

The Nature of Learning Disabilities

Learning-disabled (LD) children are defined as having received adequate instruction, do not have significantly below average intelligence as measured by psychometric intelligence tests, have no emotional factors impeding learning, and yet have failed to learn (Cordoni, 1987). Intuitively, it seems unlikely that a child of average to above average intelligence would have difficulty in the acquisition of academic skills. Yet, this handicap occurs in about 5% of the general population, affecting males more frequently than females (Farnham-Diggory, 1986). Several theories, definitions, assessment methods, and types of intervention have been put forth, with only minimal gain in the understanding of learning disabilities. In reviewing the issues and problems in the field of learning disabilities, it is clear that scholars, teachers, parents, and the children themselves are unclear as to the true nature and cause of this handicap.

Definitional Problems in Learning Disabilities

The term learning disability is a poorly defined diagnostic classification covering children who are not succeeding academically despite average intelligence. One

reason for the difficulty in defining learning disabilities is that they encompass a wide variety of scholastic problems. The Education for All Handicapped Children Act of 1975 (Public Law 94-142) provides one commonly used definition of learning disabilities (Federal Register, 1977):

The term "children with specific learning disabilities" means those children who have a disorder in one or more of the basic processes involved in understanding or in using languages, spoken or written. The disorder may manifest itself in an imperfect ability to listen, think, speak, read, write, spell, or do mathematical calculations. Such disorders include conditions such as perceptual handicaps, brain injury, minimal brain dysfunction, dyslexia, and developmental aphasia. This term does not include children who have learning problems which are primarily the result of mental retardation, of emotional disturbance, or environmental, cultural, or economic disadvantage.

A broader definition is supplied by the Association for Children and Adults with Learning Disabilities:

A chronic condition of presumed neurological origin which selectively interferes with the development, integration, and/or demonstration of verbal and/or non-verbal abilities. Specific Learning Disabilities exist as a distinct handicapping condition in the presence of average to superior intelligence, adequate sensory and motor systems, and adequate learning opportunities. The condition varies in its manifestations and in degree of severity. Throughout life, the condition can affect self-esteem, education, vocation, socialization, and/or daily living activities. (cited in Cordoni, 1987, p. 8)

A third definition is furnished by the National Joint Council for Learning Disabilities:

Learning disabilities is a generic term that refers to a heterogeneous group of disorders

manifested by significant difficulties in the acquisition and use of listening, speaking, reading, writing, reasoning or mathematical abilities. These disorders are intrinsic to the individual and presumed to be due to central nervous system dysfunction. Even though a learning disability may occur concomitantly with other handicapping conditions (e.g., sensory impairment, mental retardation, social and emotional disturbance) or environmental influences (e.g., cultural differences, insufficient/inappropriate instruction, psychogenic factors), it is not the direct result of those conditions or influences. (cited in Michelson, 1990, p. 6)

These definitions have several points in common: (a) learning disabilities are individualized disorders with a wide variety of symptoms; (b) the cause of learning disabilities is assumed to be a neurological dysfunction; and (c) neurological dysfunctions are manifested in processing disorders which interfere with learning. Sound research, assessment, and intervention with LD children must consider all three points.

Research Problems in Learning Disabilities

The knowledge base concerning learning disabilities has been developed on a foundation of tradition rather than empirical analysis (Baker, Ceci, & Herrman, 1987; Fletcher & Morris, 1986; Hammill, 1990). Research in the area of learning disabilities, although still correlational, is only now beginning to move from descriptive to explanatory investigations of the disorder. If the study of learning disabilities is to investigate the neurological inefficiencies and processing deficits implied by the definitions, then the classification of disabled learners

must become more exact, moving beyond exclusionary definitions and heterogeneous samples to descriptive definitions and subtyped samples (Reschly & Gresham, 1989).

Investigation of the nature of learning disabilities is hampered by the exclusionary nature of the definition. As defined, an LD child has difficulty learning, but does not have low intelligence; does not have emotional factors interfering with learning; does not have sensory deficits; has not received inadequate instruction; and is not culturally, environmentally, or economically disadvantaged. In other words, LD children are identified by a process of exclusion. Such a process provides little insight into the nature or cause of the disorder (Hammill, 1990). LD children are assumed to have deficits in information processing; however, there are no assessment instruments validated for the purpose of measuring information-processing deficits (Fletcher & Morris, 1986; Reschly & Gresham, 1989). In other words, identifying processing deficits in LD populations relies more on inference than on direct data.

In addition, nearly every study on LD children has been marked by poorly defined samples (Siegel & Heaven, 1986). The majority of research comparing children with learning disabilities to non-LD children has been hindered by the failure to consider the heterogeneity of the LD population (Epps, Ysseldyke, & McGue, 1984; Fletcher & Morris, 1986;

Kavale & Forness, 1987; Reschly & Gresham, 1989). Even in adequately designed studies, in which an LD group was compared to a non-LD control group, the LD group was defined as those children being served in a special education program designed for LD children (e.g., Cermak, 1983; Lorschach & Gray, 1986), which often contained children exhibiting a wide range of learning and emotional difficulties (Fletcher & Morris, 1986). Such poorly defined groups have led to studies with heterogeneous samples, thus leading to studies which cannot be clearly interpreted and do not generalize beyond the sample.

Subtyping of LD samples is therefore necessary to conduct generalizable research. Those efforts that have identified subtypes of learning disabilities by using neuropsychological assessment (Bakker, 1984; Lyon, 1982), psychometric techniques, or standardized achievement test profiles (Fletcher, Satz, & Morris, 1984), have met with moderate success. Although several methods of subtyping LD samples have been validated and are available, few studies investigating differences between LD and non-LD samples have applied these techniques to reduce heterogeneity in LD samples (Farnham-Diggory, 1986). For example, Rourke (1985) isolated three distinct groups of LD children which were identified by profile analysis of the Wide Range Achievement Test (Jastak, 1984). The three types were (a) subjects who were uniformly below the 19th percentile in reading,

spelling, and arithmetic (Reading--Spelling--Arithmetic); (b) subjects earning Arithmetic scores 1.8 grade equivalent years above the Reading and Spelling scores (Reading--Spelling); and (c) subjects who earned Arithmetic scores at least two years below their Reading and Spelling scores (Arithmetic). This method illustrated that LD children can be subtyped into a generalized learning disability and specific learning disabilities in language or arithmetic.

Thus, this suggests that the information-processing deficits manifested in a language learning disability are different from those manifested in an arithmetic learning disability. The investigation of children with specific learning disabilities in language or arithmetic may provide more insight into the isolation and identification of information-processing deficits, than treating the population of children labelled LD as a homogeneous one (Farnham-Diggory, 1986).

Information Processing

Areas of research that may shed light on the underlying nature of learning disabilities are information-processing theories and reaction-time (RT) methodology, which have the potential to become powerful tools for moving beyond exclusionary definitions and heterogeneous samples in the investigation of the nature of learning disabilities (Jensen, 1987a). In this section, relevant information-processing theory and its application to the study of

learning disabilities are reviewed.

Information-processing Theory

Theories of information-processing abound, but most propose a model positing a limited capacity of short-term memory as a central tenet. The single channel hypothesis of memory is of primary importance for the study of the relationship between RT and cognition (Welford, 1980). In these theories, the conscious brain is seen as a limited capacity information-processing system. The number of operations which can be performed on information entering the system via sensory input or information previously stored in long-term memory (LTM) are limited (Dempster, 1985). Incoming sensory information can only be stored in short-term memory (STM) for a limited duration (durability) and in a limited amount (capacity) without rehearsal or storage of information into the virtually limitless LTM (Campione & Brown, 1978). The process of storing information in LTM takes time and uses channel capacity. If the information in STM is not processed into LTM it will decay, or the capacity of the STM will be overtaxed due to interference from incoming stimuli.

Speed of information processing is advantageous in that more processes can be performed per unit of time without overloading the limited capacity and durability of the system (Jensen, 1987a). Such an overload creates an information-processing system failure which results in the

inability to understand the elements necessary for successful completion of the cognitive task. As information becomes increasingly complex and a greater number of manipulations are required, an increasing amount of time is demanded to completely process the information and speed of elemental processes becomes increasingly important (Eysenck, 1987; Welford, 1980). Thus, the speed with which information can be processed is a major factor in determining the amount of incoming information which is processed into LTM and how much information is lost (Welford, 1980). In addition to this factor, several psychologists have hypothesized that over a period of time small differences in speed of information processing result in great individual differences in stored knowledge and higher-order processes (e.g., Campione & Brown, 1978; Eysenck, 1979).

Speed of Information Processing and Intelligence

The study of speed of information processing variables and individual differences in cognitive ability is certainly not new. Reaction time (RT) is one of the oldest experimental techniques in psychology. Boring (1957) called the period from 1870 to 1901 psychology's period of mental chronometry. F. C. Donders from 1869 to 1876 and Wilhelm Wundt from 1887 to 1894 used RT as a tool to investigate common psychological processes (Boring, 1957). Francis Galton and James McKeen Cattell applied RT methods to

investigate individual differences in intelligence (Galton, 1883). More specifically, RT allowed scientists to investigate physiological processes thought to underlie intelligence by measuring the speed of apprehension of a visually presented stimulus (Boring, 1957). Galton (1883) believed that many physical attributes were related to intelligence, including: visual and auditory acuity, physical strength, pitch discrimination, reaction time, and the discrimination of weights. However, the measurement of speed of apprehension of stimuli gained the most attention and support as a mental ability test (Boring, 1957; Galton, 1883). Judged by current standards the methods and apparatuses used were crude and inexact, which created a great deal of error in measurement. The first period of mental chronometry ended in 1901, when Clark Wissler (1901), a student of Cattell's, used the newly invented method of correlation to examine the relationship between RT and school grades. He discovered that the correlation between the two was an insignificant--.01. He concluded that RT was not related to individual differences in intelligence. There are several factors that led to the spuriously low correlation and premature conclusion, including: a sample restricted in range of intelligence (Columbia University freshmen); an unreliable apparatus in need of frequent recalibration; the use of college grades (which are highly unreliable) as the criterion variable; and the use of simple

reaction time alone. Despite the shortcomings in Wissler's study, interest in research on RT and intelligence declined dramatically after it was published (see MacFarland, 1928 for a review and critique of these early studies). Another event which contributed to the decline in the study of RT was the emergence of psychometric testing, pioneered by Alfred Binet, which became the major technique for investigating intelligence (Boring, 1957).

There has been renewed interest in the study of RT in the field of individual differences and intelligence since the mid-1970s. The rise of cognitive psychology, innovations in theory of measurement, and the improvement in technology have set the stage for the investigation of physiological causes of individual differences in cognitive functioning. The primary criterion for studies of RT and cognitive ability is the first unrotated factor or component of a battery of psychometric cognitive tests, also known as the general factor or psychometric g (Eysenck, 1979). This is derived, in part, from the fact that all tests involving cognitive functioning are positively correlated (Jensen, 1985). Individual differences on IQ tests are primarily accounted for by differences in g . Psychometric g can best be described as general intelligence. RT tasks that measure information-processing speed and efficiency, have provided important information in the investigation of individual differences in g (Jensen, 1985).

Reaction time (RT) is believed by many to be an excellent operationalization of the speed of information-processing variable that plays such a key role in the single channel hypothesis (e.g., Jensen, 1982, 1985; Welford, 1980). These RT tasks are usually completed in less than 1500 milliseconds (ms), with the simplest tasks spanning less than 500 ms. This is important in that the threshold of cognitive awareness is at approximately 600 ms (Chi & Gallagher, 1982). Thus, many RT tasks are completed prior to cognitive awareness, at which point knowledge and problem solving strategies can be accessed. The simplest RT tasks minimize knowledge content and problem solving strategies. They also do not seem to improve with practice (Jensen, 1982). However, complex RT tasks, that is ones that are completed in 900 ms to 2000 ms, involve access to knowledge and strategies demonstrate significant practice effects (e.g., Rabbitt, 1989). In sum, this indicates that knowledge and strategies are not related to individual differences on simple RT tasks, but are related on more complex tasks.

The simplest RT tasks are referred to as elementary cognitive tasks (ECTs). These tasks are so simple that normal subjects respond with accuracy nearing 100% in untimed conditions. Given that there are limited practice effects and that responses to RT stimuli take place below the threshold of conscious awareness, and that there are low

error rates; these tasks are presumed to tap into hardwired, microlevel processes that appear to be only minimally influenced by knowledge and strategies (Eysenck, 1979; Jensen, 1987c). These processes are believed to have a neurological substrate, but the physiological mechanism(s) for such processes have been hypothesized, not empirically isolated (Hendrickson, 1982; Vernon & Mori, 1989).

Information Processing and Learning Disabilities

All cognitive tasks, require three categories of cognitive functioning: (a) task-relevant knowledge; (b) problem solving strategies; and (c) information-processing ability (Jensen, 1987b). Psychometric instruments of intelligence and academic achievement clearly involve all three cognitive abilities (Jensen, 1988). Although children experiencing academic difficulties may be failing for any number of reasons, learning disabilities are theorized to result only from deficits in information-processing ability. Deficits in task-relevant knowledge and problem solving strategies can be remediated through instructional interventions (Levine, Preddy, & Thorndike, 1987; Swanson, 1982), whereas deficits in information processing are assumed to be due to immutable neurological inefficiencies (Hynd & Cohen, 1983).

As mentioned above, RT tasks are significantly correlated with *g*, moreover most RT tasks are also intercorrelated (Larson & Saccuzzo, 1989). This has led

some investigators to hypothesize that speed of information processing stems from a unitary process that underlies g (Larson & Saccuzzo, 1989). However, evidence strongly suggests that g consists of a small number of independent processes (Jensen, 1987b; Kranzler & Jensen, in press). In the case of an LD child, perhaps a small number of the cognitive processes are deficient, whereas the remainder are intact. Hence, they perform adequately on some tasks and poorly on those that are related to deficient processes. Compare the information processing of an LD child to an individual of low intelligence in whom all cognitive processes may be deficient and who performs poorly on nearly all complex tasks (Jensen, 1987a; Pellegrino & Kail, 1982). A few hypothesized processes are stimulus apprehension, stimulus encoding, spatial discrimination, STM search, and retrieval from LTM (Jensen, 1987b; Morrison, Giordani, & Nagy, 1977). All of these processes are involved in performing complex tasks, such as those included on intelligence tests. Because of this, children with specific learning disabilities may have approximately normal intelligence, a more scattered profile of subtest scores on a multifaceted test battery than non-LD peers, and weaknesses in some specific academic skills, yet average performance on other academic skills (Hynd & Cohen, 1983). How severe and widespread the academic difficulties are may depend on which and how many elementary cognitive processes

are affected (Ackerman & Dykman, 1982). At this point, the cognitive processes have not been identified, nor have the number of processes been determined. According to this theory, if the RT tasks tap the processes in the LD subject that are deficient, the LD subject will likely respond more slowly and with more intraindividual variability. Also individuals with low intelligence may not differ from LD children in a qualitative sense as assumed by the notion of deficient specific processes. The differences between LD and low intelligence individuals may be one of degree rather than kind. Some research on reading difficulties, support this explanation (e.g., Bryant, McIntire, Murray, & Blackwell, 1983; Wiig, Semel, & Nystrom, 1982). If this idea is correct then LD and non-LD subjects will differ on most RT tasks rather than on a specific few.

It is also important to note that even though RT tasks are intercorrelated, it does not make using RT batteries to identify deficient processes in LD children less useful. A high correlation among tests that measure distinctly different processes can be especially useful in making differential diagnosis of LD children. Jensen (1987a) provides a useful analogy:

A physical analogy would be the fact that a person's right and left arms are clearly different appendages and yet are almost perfectly correlated in a physically normal population. The regression equation for predicting left arm length from right arm length in a normal population could be used to discover "outliers." (p. 84)

Employing a subject pool of LD children, who are assumed to be deficient in one or more cognitive processes, may help to shed light on the multiple processes of intelligence and differential diagnosis of LD children.

In sum, the ECTs, which reduce the effects of knowledge and problem solving strategies, may provide insight into the neurologically based processing deficits of LD children. Because ECTs have been theorized to tap into hardwired, microlevel processes these are tasks potentially useful in the investigation of the nature of learning disabilities (Hynd & Cohen, 1983).

Reaction-time Methodology

Reaction-time Tasks

Given that there are many types of RT tasks, that the simplest ones have shown no significant practice effects, that normal subjects make few errors (Jensen, 1982), and that response time is less than the threshold of cognitive awareness (Chi & Gallagher, 1982), RT tasks are assumed to reflect individual differences in hardware. The simplest RT tasks are called elementary cognitive tasks (ECTs). These tasks are theorized to tap into the most elementary of cognitive processes (Jensen, 1987b).

In this section the ECTs used in this experiment are briefly described. See Chapter 2 for a detailed description of the procedures.

Hick paradigm. The Hick paradigm is named after Hick's

Law, which states that reaction time increases as a linear function of the amount of information presented in a stimulus array expressed in bits, $\log_2 n$, or the amount of information necessary to reduce uncertainty by half (Hick, 1952). The slope of the linear function is interpreted as a measure of processing efficiency. More efficient processing should, thus, result in shallower slopes (Jensen, 1987a). The intercept is interpreted as an estimate of the time required for the processes of sensory registration of the stimulus and time to initiate response. In other words, the intercept yields information about both efferent and afferent nerve conduction.

The Hick paradigm measures both simple and choice RT. The data from this paradigm is presumed to include components such as sensory and muscle lag, apprehension and encoding of the stimulus, and response production; plus decision time in the choice RT conditions. Studies have consistently shown moderate correlations between with median RT and g . However, intraindividual variability in RT, the standard deviation of subjects' RTs, is often more highly correlated with g than RT itself (Jensen, 1987b; Larson & Alderton, 1990; Larson & Saccuzzo, 1989).

Odd-man-out (Oddman) paradigm. The Oddman paradigm involves the same processes as the Hick paradigm, but with the addition of spatial discrimination. The Oddman is more highly correlated with g than the Hick. Like the Hick,

intraindividual variability correlates higher with g than median RT (Frearson & Eysenck, 1986).

Memory search. The memory search paradigm involves sensory and muscle lag, apprehension and encoding of stimulus, response production, and the speed of scanning information in STM for successful completion of the task (Sternberg, 1966). For this ECT, the stimulus array to be remembered varies between 1 and 7 digits. Reaction time increases linearly as a function of n of the stimulus array rather than as a function of bits as in the Hick paradigm. The use of a mean RT across set sizes provides a good estimate of the speed of scanning information in STM (Harris & Fleer, 1974; Kranzler & Jensen, in press).

Visual search. This paradigm demands similar processes as the memory search paradigm; however, the visual search paradigm minimizes the role of STM and involves the visual scanning of a stimulus array (Neisser, 1967). For this ECT the stimulus array to be searched varies between 1 and 7 digits. As in the memory search RT increases linearly as a function of n of the stimulus array. The use of a mean RT across set sizes provides a good estimate of the speed of scanning information in STM (Harris & Fleer, 1974; Kranzler & Jensen, in press). Visual search and memory search are correlated nearly as high as reliability permits in normal populations (Jensen, 1987c).

Semantic verification task. The semantic verification

task (SVT) measures the speed of rule-based decision making (Baddeley, 1968). More complex processes, including retrieval of linguistic information from LTM (knowledge), are involved in the SVT than in previously described RT tasks (Jensen, 1987a).

Issues in Reaction-time Methodology

There are methodological issues in RT tasks which include such potentially confounding factors as practice effects, retinal displacement, response bias, speed-accuracy trade-off, reliability, and stability.

Practice effects and retinal displacement. Practice effects, or learning, is an issue in the RT field (Longstreth, 1984). If intelligence tests reflect learning ability, and subjects are improving on RT with practice at differential rates as a function of learning ability, then it is learning ability rather than speed of information-processing that is responsible for the RT-intelligence test relationship (Jensen, 1987c). The preponderance of the evidence does not support the existence of practice effects, yet there are some contrary findings. Longstreth (1986) used a substantially different apparatus than Jensen, and found that practice effects transferred from one block of trials to another. A visual attention effect, known as retinal displacement, was presented by Longstreth (1984). Retinal displacement was described as the detrimental effects of attention on stimuli which are displaced 12 to 15

deg from the point of foveal attention. Kranzler, Whang, and Jensen (1988) investigated the issues of retinal displacement and practice effects. Practice effects were not found. Although significant retinal displacement effects were found, they accounted for less than 2% of the variance. Therefore, the effects of retinal displacement are not considered to be a theoretically important source of individual differences on the Hick paradigm. Widaman and Carlson (1989) failed to replicate the results of Kranzler et al. using a similar, but not identical apparatus. Widaman and Carlson implicated practice effects as a confounding variable in individual differences in RT, although the data do not support that strong conclusion. In sum, although retinal displacement and response bias do not appear to account for a significant amount of variance in the results of RT studies, the issue of practice effects is unresolved (Welford, 1986). Any RT study should consider the possibility that practice effects could affect results (Rabbitt & Banjeri, 1989; Widaman, 1989).

Response bias. Response bias is defined as differential preference or response tendencies for different light button positions (Jensen, 1987c). This variable constitutes a part of the subject's error variance. The amount of variance accounted for by the Subjects x Positions interaction is 19% (Jensen, 1987c). Compare this with the percentage of the total variance of the main effect of

Position of only 1% and main effect of Subject of 80% (Jensen, 1987c). This amount of variance is mostly averaged out since light positions are equally likely to be the correct response and there are 15 or more trials at each set size.

Speed-accuracy trade-off. Detterman (1987) suggested that subjects frequently sacrifice accuracy for speed, or vice versa, resulting in a speed-accuracy trade-off. This is another potentially confounding variable in the use of RT tasks. Jensen (1987c) refuted this criticism by noting that error rates and RT are positively correlated. In other words, subjects with shorter RTs tend to make fewer errors than subjects with longer RTs. The speed-accuracy trade-off, if it does exist, does not play a significant role in individual differences (Jensen, 1987c).

Reliability. Reaction-time tasks have high levels of internal consistency. Split-half reliabilities have been reported to range from $r_{xx}=.93$ to $r_{xx}=.79$ on the Hick (Jensen, 1987c) and from $r_{xx}=.88$ to $r_{xx}=.74$ on the Oddman (Frearson & Eysenck, 1986). Reliability tends to increase with the number of trials as per the Spearman-Brown prophecy formula.

Stability. The test-retest reliability of the Hick and Oddman paradigms has been investigated by Michelson (1990). With 24 hours between sessions, the stability of the simple RT on the Hick paradigm ranged from .861 to .931. The

Oddman paradigm had higher test-retest reliabilities (.862 to .947). All figures are corrected with the Spearman-Brown prophecy formula. The VS and MS paradigms both have high levels of stability in both reaction time and movement time parameters. Stabilities range from .902 for MS reaction time to a low of .781 for MS movement time (Jensen, 1985; Neisser, 1967). Intraindividual variability was not as stable, with a stability of .765 for MS and .674 for VS (Jensen, 1985; Neisser, 1967). Test-retest reliability has not been calculated for the SVT; however, stability is unlikely to be much different from the other RT tasks (Jensen, Larson, & Paul, 1988). Although RT is sensitive to changes in body temperature, fatigue, and attention, which influence stability; the various parameters have been shown to be relatively stable over a 24 hour time period.

Summary. Many potential problems with RT methods have been proposed. However, after carefully examining the literature, it is clear that the potentially confounding factors in the study of individual differences in RT have not been shown to be systematically related to individual differences in RT.

Reaction Time and Intelligence

In the mid-1970s, the use of RT to investigate psychometric g began to increase (Jensen, 1985). A great many studies during the next 15 years revealed negative correlations (higher intelligence covaries with shorter

median reaction times) between intelligence and the parameters of various RT tasks (see Vernon, 1987). Typical correlations of intelligence and RT are simple reaction time (Hick paradigm), $r = -.19$ (Jensen, 1987c); choice reaction time (Hick paradigm) (Jensen, 1987c), $r = -.26$; semantic verification tasks, $r = -.26$ (Jensen, Larson, & Paul, 1988); and the Oddman paradigm, $r = -.60$ (Frearson & Eysenck, 1986). RT tasks effectively discriminate between retarded and non-retarded individuals, and other ability groups on several elementary cognitive tasks, such as a version of the Memory Search task (Harris & Fleer, 1974), the Hick paradigm (Jensen, 1987c; Michelson, 1990; Vernon & Jensen, 1984), and the Oddman (Michelson, 1990). The relationship between ECTs and intelligence has been corroborated by over 50 studies published within the past 15 years and is well established (Vernon, 1990).

Reaction Time and Learning Disabilities

Efforts to understand information-processing deficits have led to the use of RT in the study of learning disabilities. Previous studies of RT and learning disabilities suffer from generally poor selection criteria for LD groups, poor design, and extremely complex RT tasks. The majority of the efforts to use RT in the investigation of learning disabilities have involved tasks with relatively high levels of knowledge and strategy content under timed conditions (e.g., Bauer, 1979; Culbert, 1982; Eakin &

Douglas, 1971; Lorschach & Gray, 1986; Pellegrino & Kail, 1982; Spring & Greenberg, 1972; Wiig, Semel, & Nystrom, 1982) or the recall of a tachistoscopically presented display of numbers, letters, or words (e.g., Bryant, McIntire, Murray, & Blackwell, 1983; Ellis & Miles, 1987; Scott, 1986; Spring & Capps, 1974). Although these studies may not reflect hardwired differences by reducing the effects of knowledge and strategies, the results of this research have shown that LD children are consistently slower on timed tasks than their non-LD peers (Jensen, 1987a). Discrimination between LD and non-LD samples using a battery of ECTs has seldom been attempted.

Auxter (1971) used a simple reaction time task (similar to the SRT condition of the Hick paradigm) with LD children. Selection of the LD sample was not explicitly described. However, the children were all under six years of age. The sample was composed of 17 LD and 17 non-LD children. The task required a simple motor response to a visually presented stimulus, it did not separate decision time from movement time. The task itself consisted of only 10 trials, creating suspect reliability in the measurement. No significant differences were found between groups. This result is not surprising given the relative lack of power and suspect reliability in this design.

Spring (1971) investigated the rate at which reading disabled and non-handicapped children made discriminations

about visually presented letters. Reading disabled children were slower in the letter matching task than non-handicapped children. After several trials the RT for non-handicapped subjects decreased, presumably due to practice effects. The RT for reading disabled subjects increased. Spring attributed the increase in RT to shorter attention span in reading disabled subjects.

Spring (1976) used digit naming speed to discriminate dyslexic children from non-handicapped children. Digit naming speed discriminated between the two groups with 93% accuracy. Spring concluded that differences in digit naming speed were due to differences in phonetic coding speed.

In a recently completed dissertation, Michelson (1990) administered the Hick and Oddman paradigms to LD and non-LD children, matched for age and gender. The LD group demonstrated significantly longer latencies on the choice RT on the Hick and Oddman paradigms. The LD group had greater intraindividual variability on the 0-bit condition of the Hick paradigm when compared to the non-LD group. Hick and Oddman combined intraindividual variability (RTsd) was the only variable that discriminated between groups at a level better than chance, 64% of participants was correctly assigned to their respective groups. Given that errors are have been rare in non-handicapped populations, it is noteworthy that LD children made more errors on the Oddman task than the non-handicapped group.

Statement of Problem

The problem was to compare groups of subtyped LD children to non-LD children using RT tasks. A secondary problem was to isolate and identify information-processing deficits in a learning disabled sample using RT methodology. Five RT tasks, each of which tap ostensibly different processes, were used. Heterogeneity in the LD sample was reduced by dividing the sample into three groups: children labelled as learning disabled only in reading, children labelled learning disabled only in mathematics, and children with no reported learning problems. The sample was further restricted by using criteria which are described in detail in Chapter 2. The possibility that ECTs, which may tap into elementary processes, discriminate among LD-Reading, LD-Math, and non-LD groups provides the opportunity for investigations of learning disabilities to move beyond exclusionary descriptions toward a description of the true nature of this disorder.

Description of Study

The present study used a battery of RT tasks to discriminate among LD children with reading deficits, LD children with math deficits, and non-LD children matched for intelligence and age. The RT tasks used were the Semantic Verification Task (SVT) (Baddeley, 1968; Jensen, Larson, & Paul, 1988), Oddman paradigm (Frearson & Eysenck, 1986), Hick paradigm (simple and choice reaction time) (Jensen &

Munro, 1979), Memory Search (Sternberg, 1966), and Visual Search (Neisser, 1967).

The present study contributes to the literature on reaction time and learning disabilities by replicating and extending Michelson's investigation. Like Michelson's dissertation, this study used the Hick and Oddman RT paradigms to investigate LD children. Unlike this and other studies, the memory search, visual search, and semantic verification task paradigms were used as well. Another contribution was the use of a more stringently selected and subtyped sample. In addition to meeting criteria for learning disabilities, as defined by the State of Florida, subjects in the sample were identified by their teachers as having no behavior problems, were not prescribed psychotropic medication, and had IQs within two standard deviations of the mean. The LD children were also subtyped into reading disabled and mathematics disabled groups. The use of a more extensive battery of RT tasks and a stringently selected and subtyped sample present improvements over previous studies. Such improvements may prove helpful in the investigation of information processing in LD children.

Rationale

Reaction Times

Reaction-time tasks measure the speed and efficiency of information-processing. Learning disabled children are

defined as those who have deficient cognitive processes. Individuals with deficient processing are hypothesized to transmit information via less efficient neural routes, activating more neural elements than individuals with efficient processes (Haier, Siegel, Nuechterlein, Hazlett, Wu, Paek, Browning, & Buschbaum, 1988; Jensen, 1982). Signals transmitted via these less efficient routes result in increased RT. Each RT task demands ostensibly different information processes (e.g., stimulus apprehension, stimulus encoding, STM memory search, retrieval from LTM, choice). If the deficient process(es) is(are) required for successful completion of the RT task, inefficient processing will occur. On RT tasks, inefficient processing will manifest itself in a longer median response latency on tasks which tap into the processing deficit(s) of the individual. If LD children are defined as having inefficient information processes, it is likely that these children will have greater RTs than non-LD children.

Intraindividual Differences

Intraindividual differences (RTsd) are often more strongly correlated with g than RT itself (Jensen, 1987c). In other words, more consistent performance (smaller RTsd) is associated with high intelligence. This suggests that speed is not a fundamental variable, but that there are processes which are even more fundamental that create intraindividual differences in RT.

According to one theory information processing is a function of transmission of information throughout the cortex (Eysenck, 1982; Hendrickson, 1982). Transmission occurs via propagation of signals through a series of neurons and synapses. At any one synaptic point errors in the correct recognition of the signal may occur (Eysenck, 1987). Successful processing of information is, thus, probabilistic. The probability of error-free transmission at any one of the synaptic recognition points is R , and the probability that all recognitions will be error-free, resulting in successful processing, is R^N , with N as the number of synaptic recognition points. Individuals with more inefficient processing tend to transmit information via longer routes with greater numbers of synaptic recognition points than individuals with efficient processes (Haier et al., 1988; Hendrickson, 1982) which means greater N and increased probability of error. In terms of RT, the greater probability of error results in the greater variability in RT. Moreover, the slowest RTs are more likely to discriminate individuals with efficient processes from those with inefficient processes than the fastest RTs (Kranzler, in press; Larson & Alderton, 1990). If LD children do indeed have inefficient information-processes, it is likely that they will have greater intraindividual differences than non-LD children.

Response Errors

Response errors are an infrequently investigated variable in RT research. Humphreys (1989) suggests that response errors may be a better predictor of *g* than latency or intraindividual variability. In normal populations, response errors on ECTs are quite rare (less than 5%). They occur more frequently on complex tasks.

The rationale is that LD children make decisions before completely processing information (Bryant, McIntire, Murray, & Blackwell, 1983; Nettlebeck & Brewer, 1981). There is evidence suggesting that mildly mentally retarded children made fewer response errors when forced to delay decision making (Nettlebeck & Brewer, 1981). If the incomplete information explanation is the cause of increased response errors, one can expect a speed-accuracy trade-off to occur, that is if the subject is trying to respond as quickly as possible at the expense of accuracy. Frequently, the types of errors that LD children make suggest that decisions have been made on too little information (Rourke, 1985).

Premature decision making and impulsivity frequently occur concurrently with learning disabilities and may be caused by the same neurological inefficiencies (Hynd & Cohen, 1983; Morrison, Giordani, & Nagy, 1977; Reschly & Gresham, 1989; Rourke, 1985).

Movement Times

Movement time (MT), the interval from initiation of the

response to completion of the task, is considered to be less theoretically important than the other RT parameters (Jensen, 1987c). Movement time does not seem to reflect central information processing, but, rather, more peripheral sources of variance (Jensen, 1985). However, as MT frequently demonstrates a modest correlation with g (Jensen, 1987c), this parameter will also be examined.

Hypotheses

The main hypothesis is that RT variables (reaction time, intraindividual differences, and response errors) derived from the above listed battery of RT tasks will effectively discriminate LD-Reading, LD-Math, and non-LD groups. The specific hypotheses are:

1. Children with learning disabilities in reading will show longer mean median latencies (slower processing time) and greater intraindividual variability (greater inconsistency) on the RT tasks demanding retrieval of information from LTM and speed of rule-based decision making. Thus, the LD-Reading groups will show longer mean RTs and greater standard deviations (RTsd) than either the LD-Math or the non-LD groups on the Semantic Verification Task (SVT).

2. Children with learning disabilities in both reading and mathematics will show longer mean median latencies and greater intraindividual variability in cognitive tasks demanding non-symbolic information processes, such as

stimulus apprehension and encoding, stimulus discrimination, and decision making. Thus, the LD-math and LD-reading groups will show a greater RTsd and RT on the Oddman and Hick paradigms than non-LD groups.

3. Children with learning disabilities in reading and mathematics will demonstrate longer response latencies and greater intraindividual variability in memory tasks than non-LD children. Thus, the LD-Math and LD-Reading groups will show greater RT and RTsd than the non-LD group on Memory Search and Visual Search tasks.

4. Children with learning disabilities in reading will have markedly higher error rates on the SVT than non-LD children or LD-math children.

5. Children with learning disabilities in both mathematics and reading will have markedly higher error rates than non-LD children on the Oddman paradigm, Memory Search, and Visual Search.

6. Because learning disabilities are considered a central processing deficit and MT reflects more peripheral sources of variance no significant differences among group in movement time will occur on any of the ECTs.

CHAPTER 2 METHODS

Subjects

Characteristics

The sample of 96 subjects was divided into three groups of 32 each. The first group consisted of children who had a specific learning disability in only mathematical calculation skills (LD-Math); the second group consisted of children having a specific learning disability only in reading skills (LD-Reading); and the third group consisted of children without an identified learning disability (non-LD).

All subjects were male. Subjects were assigned to triads (one LD-Reading, one LD-Math, and one non-LD subject) based upon like intelligence (Otis--Lennon Learning Aptitude Test) and age. The age of subjects is a major consideration in investigations of RT (Chi, 1977) because RT decreases over age until young adulthood, at which point speed of information processing tends to decrease (RT increases) throughout the lifespan (Chi & Gallagher, 1982; Rabbitt, 1984). Thus, subjects must be matched for age or else age may confound results (Chi, 1977; Keating & Bobbitt, 1978). The subjects each had a measured intelligence quotient (Otis Lennon Scholastic Aptitude Test) within two standard

deviations of the mean, subjects were not prescribed psychotropic medication during the time of data collection, and the subjects' teachers reported no pattern of behavior problems. Subjects in the non-LD group had not been identified by the school system as having a learning disability and were making satisfactory academic progress, according to teacher reports.

To lessen the problem of heterogeneity within groups, the following criteria were used to further define the LD-Reading groups: subjects had been identified as learning disabled by the school system for purposes of educational placement, at least a 15 point discrepancy between Verbal and Performance Scales of the Wechsler Intelligence Scale for Children--Revised (WISC--R), at least a 15 point discrepancy between the Full Scale Intelligence Quotient (WISC-R) and a standardized test of reading achievement (Woodcock--Johnson Achievement Battery), and also had less than a 15 point difference between the Full Scale Intelligence Quotient and a standardized test of mathematics achievement.

Similarly, for the LD-Math group subjects had been identified as learning disabled by the school system for purposes of educational placement, at least a 15 point discrepancy between Verbal and Performance Scales of the Wechsler Intelligence Scale for Children-Revised (WISC-R), at least a 15 point discrepancy between the Full Scale

Intelligence Quotient (WISC--R) and a standardized test of mathematics achievement (Woodcock--Johnson Achievement Battery), and also had less than a 15 point difference between the Full Scale Intelligence Quotient and a standardized test of reading achievement. Descriptive statistics of the sample are presented in Table 1.

Sampling

Subjects were obtained from five junior high schools and the pediatric clinic of a health care facility in northeast Florida. Teachers and psychologists were made aware of the present study and referred possible subjects. An informed consent form was then sent home with the student to be signed by the student and the parent(s) or guardian. After the informed consent form was completed the student's academic records were examined to determine eligibility for the study. If the subject met eligibility criteria, a memo was sent to the parent(s) or guardian as notification of further testing. Administration of the RT tasks was then conducted at the child's school. All subjects were unpaid volunteers and were told that they could withdraw at any time.

One hundred and eight children were identified by teachers as having a specific learning disability in mathematics or a specific learning disability in reading. Eighty-five children without identified learning problems

Table 1

Characteristics of LD-Reading, LD-Math, and Non-LD Groups
(N=32 per group)

Variable	LD-Reading		LD-Math		Non-LD	
	Mean	<u>SD</u>	Mean	<u>SD</u>	Mean	<u>SD</u>
Age (years)	12.5	1.4	12.9	1.3	12.1	1.2
OLSAT	101.1	14.1	102.6	14.2	103.3	13.7
WISC-R (V)	87.5	12.4	87.2	13.1		
WISC-R (P)	104.1	13.2	104.3	13.5		
WISC-R (FS)	95.1	10.1	95.5	9.7		
WJ-Reading	74.0	8.6	91.4	10.3		
WJ-Math	88.3	9.9	76.6	9.2		

were nominated by teachers. Informed consent forms were sent home with all potential subjects. One hundred and twenty-nine informed consent forms were signed and returned by parent(s) or guardian (66.8%). Seventeen subjects were not used because they failed to meet the criteria of no pattern of behavior problems as reported by their teacher. Four subjects were not used because the criterion of no current prescription for psychotropic medication was not met. Ten subjects were eliminated because an adequate match in intelligence and age could not be found. Two subjects

were eliminated because they did not follow directions during administration of the RT task. These subjects had several RT parameters which were outside of three standard deviations from the mean. They were replaced with other subjects.

Procedures

Experimental Procedures

All subjects ($N=32$ triads) were administered the following reaction time (RT) paradigms: Semantic Verification Task (SVT), Oddman, Hick (which includes simple reaction time and choice reaction time), Visual Search (VS), and Memory Search (MS). The tasks were presented in a rotated sequence in order to reduce possible practice effects. The order of paradigm presentation remained constant within each triad (one LD-Reading, one LD-Math, and one Non-LD subject, matched for age and intelligence), but was systematically varied between triads to preclude the possibility of practice effects. The VS and MS tasks were on the same software program and were always presented together. For example the first triad was administered the RT tasks in the order: Hick, Oddman, SVT, and VS/MS; the next triad administered the RT tasks in the order: Oddman, SVT, VS/MS, and Hick; and so on. Subjects were instructed to respond as quickly as possible to the paradigms without making errors. Subjects were administered an untimed paper and pencil version of the SVT (Appendix), after completion

of the RT battery. This was done to verify the assumption that the SVT, like all RT tasks, had little information content and the major source of individual differences was speed of information processing and not reading ability. This assumption may not have been justified in a learning disabled population. Subjects were instructed to take as much time as necessary to complete the paper and pencil task and double check all answers.

Apparatus and Reaction-time Paradigms

The apparatus used for the Hick and Oddman paradigms was a 13 in. by 17 in. console interfaced with an IBM-compatible personal computer equipped with a timer card. The console was tilted at a 30 deg. angle. The home button was 1 in. in diameter and located in the low center of the apparatus. Eight white response buttons, 1/2 in. in diameter, were arranged equidistant from one another in a semi-circle, 6 in. from the home button. For the Hick paradigm, templates were placed on the console, which exposed the desired number of buttons: 1, 2, 4, or 8 button buttons (corresponding to 0, 1, 2, or 3 bits). Reaction time and movement time were recorded in milliseconds (ms) by an electronic timer.

For the Hick paradigm, a trial consisted of the following steps: (a) the subject depressed the home button with the subject's dominant hand; (b) a 1 s auditory warning stimulus was presented; (c) after a random interval of 1 to

4 s, one of the response buttons was illuminated; and (d) the subject moved from the home button to depress the illuminated response button. Reaction time was the time from the illumination of the response button to the release of the home button. Movement time (MT) was the time from the release of the home button to the depression of the illuminated response button. Each subject completed 60 trials, 15 for each bit condition.

The apparatus for the Oddman paradigm was identical to the Hick paradigm; however, the procedures varied slightly. A trial consisted of the following steps: (a) the subject depressed the home button; (b) a 1 s auditory warning stimulus was presented; and (c) after a random interval of 1 to 4 s, three response buttons were illuminated--two of these buttons were closer together than the third--the subject depressed the button furthest from the other two. Reaction time and movement time were recorded in the same manner as the Hick paradigm. Errors were also recorded. Errors were defined as the depression of any button other than the illuminated button furthest from the two other illuminated buttons. The task consisted of 120 trials.

Stimuli for the SVT, MS, and VS were presented on an IBM-compatible personal computer and a monochrome monitor. The response console was a 10 in. by 6 1/2 in. three button box. The home button was 1 in. in diameter and was located in the low center of the console. Two response buttons, one

green and one red, each 1 in. in diameter, were located equidistant from one another, 2 1/2 in. from the home button. The response buttons were labeled "yes" (green) and "no" (red).

For the MS paradigm, a single trial consisted of the following steps: (a) the subject depressed the home button; (b) a stimulus array of numbers from 1 to 7 digits in length was presented for 2 s on the computer monitor; (c) after an interval of 1 s, in which the screen was blank, a single probe digit was presented; and (d) the subject indicated whether the probe digit was in the stimulus array by depressing the appropriate response button ("yes" if the single digit was present in the stimulus array, "no" if not). The VS paradigm was identical to the MS, except the probe digit was presented first and followed by the stimulus array. The subject indicated whether the stimulus array contained the probe digit by depressing the appropriate response button. Reaction time, movement time, and errors were recorded automatically. Each task consisted of 84 trials.

In the SVT, the subject was asked to determine if a simple sentence accurately described the position or order of letters (eg., A Before B--ACB). A single trial consisted of the following steps: (a) the subject depressed the home button; (b) a simple sentence was displayed on the monitor; (c) after an interval of 1 s, in which the screen was blank,

3 letters appeared; (d) the subject indicated whether the simple sentence correctly described the presented letters by depressing the appropriate response button ("yes" if the sentence correctly described the letters, "no" if not). Reaction time, movement time, and errors were recorded automatically. The task consisted of 84 trials. The mean time of the presentation of the entire RT battery was 56.2 minutes with a standard deviation 6.8 minutes.

CHAPTER 3 RESULTS

The results section is divided into three parts. In the first section analyses investigating methodological issues in RT are reported. In the second, descriptive analyses of RT variables and comparisons among the groups are supplied. In the third, discriminant function analyses and corresponding canonical correlations are provided. Implications of the results are discussed in Chapter 4.

Methodological Issues

Speed-Accuracy Trade-Off

The speed-accuracy trade-off was tested by calculating Spearman product-moment correlation coefficients between the median RT and response errors for each ECT. If speed-accuracy trade-off were a confounding factor, a negative correlation between RT and response errors would be expected. Results are reported in Table 2. Positive correlations were noted for all groups and all RT tasks. Coefficients ranged from .43 to .87. There is, thus, no evidence for the potentially confounding effect of speed-accuracy trade-off.

Reliability

Reliabilities were calculated by dividing ECT trials into halves (odd-even). The odd numbered trials were

Table 2

Correlations Between Response Errors and Reaction Time

RT Task	Group		
	LD-Reading	LD-Math	Non-LD
Oddman Paradigm	.65*	.67*	.87*
Visual Search	.48*	.61*	.83*
Memory Search	.43*	.50*	.77*
Semantic Verification	.58*	.85*	.80*

*p < .005

correlated with the even numbered trials. The correlation was corrected using the Spearman-Brown prophecy formula. Reliabilities ranged from .74 to .96, as is shown in Table 3.

Descriptive and Comparative Statistics for RT Variables

All comparisons among groups were conducted by using a 4 (Order) x 3 (Groups) analysis of variance for each RT variable, with Groups as a within-subject factor and Order as the between-subject factor. In cases where the Huynh-Feldt epsilon was less than one, the Huynh-Feldt corrected F statistic was used. Matched pair, dependent sample t -tests were conducted to follow up significant Group main effects.

Table 3

Internal Consistency (Split-Half) Coefficients for
Reaction-time Variables

RT Task	r_{xx}
Hick Paradigm (0 Bit)	.74
Hick Paradigm (1 Bit)	.76
Hick Paradigm (2 Bit)	.80
Hick Paradigm (3 Bit)	.77
Oddman Paradigm	.96
Visual Search	.88
Memory Search	.84
Semantic Verification Task	.81

For the match pairs t-tests groups were collapsed across orders, because main effects for order rarely reached statistical significance, and never constituted theoretical significance.

Order Effects

The RT tasks were administered in four different orders: (a) SVT, Hick, Oddman, and MS/VS; (b) MS/VS, SVT, Hick, and Oddman; (c) Oddman, MS/VS, SVT, and Hick; and (d) Hick, Oddman, MS/VS, and SVT. Order was used as a between-subjects factor in the design. In this fashion the Order x Group interaction can be determined.

Only 2 of the 36 RT variables examined showed significant Order x Groups interaction. This number of significant interactions is approximately what would be expected by chance at the .05 level. The Oddman median RT demonstrated a significant Order x Group interaction ($F(6,56)=3.01$, $p = .0313$). The SVT MT also showed significant Order x Group interaction ($F(6,56)=2.82$, $p = .0401$). In addition, on three parameters, significant main effects for order were found. Significant main effects for order were found on the SVT paradigm MTsd ($F(3,56)=2.92$, $p = .0445$), the VS paradigm MT ($F(3,56)=3.07$, $p = .0311$), and the Oddman RTsd ($F(3,56)=3.34$, $p = .0250$). There does not appear to be any pattern to the significant results indicating theoretical significance. Moreover, this is approximately the number of variables which would be expected to be significant by chance alone.

Hick Paradigm

Reaction time. Descriptive statistics and results of dependent sample t-tests are reported in Tables 4, 5, 6, and 7 for the Hick 0-bit, 1-bit, 2-bit, and 3-bit tasks, respectively. Figure 1 represents group performance as a function of number of bits.

The Hick 0-bit condition showed significant differences among groups ($F(2,56)=8.12$, $p < .0001$). Post-hoc analysis revealed that the LD-Reading group is significantly faster than both the LD-Math and non-LD group. The Hick 1-bit

condition demonstrated group differences ($F(2,56)=3.56$, $p = .0268$) (Huynh-Feldt correction). Again, the LD-Reading and non-LD groups have significantly shorter latencies than the LD-Math group. The Hick 2-bit paradigm manifests significant differences among groups ($F(2,56)=5.02$, $p = .0122$). The LD-Reading group has significantly shorter latencies than the other groups. The Hick 3-bit paradigm did not show significant differences among groups ($F(2,56)=2.51$, $p < .0975$).

Intraindividual variability. The groups differ on intraindividual variability on the Hick 0-bit ($F(2,56)=7.04$, $p = .0011$) and Hick 1-bit ($F(2,56)=4.19$, $p = .0113$) conditions. LD-Reading evinces a significantly smaller average intraindividual variability than the other groups on both the 0-bit and 1-bit paradigms. There are also significant differences on the Hick 2-Bit ($F(2,56)=3.70$, $p = .0281$) (Huynh-Feldt correction) and the Hick 3-Bit ($F(2,56)=7.63$, $p = .0003$) conditions. In both, the non-LD exhibited significantly smaller average intraindividual variability than the other groups.

Movement time. The groups differ significantly on movement time in the Hick 0-bit condition ($F(2,56)=3.93$, $p = .0250$). The LD-Reading group was significantly faster than the other two groups. On the Hick 1-bit condition the group differences approached

Table 4

Descriptive Statistics for the Hick Paradigm 0-Bit

Group	Median		Intraindividual SD	
	RT	MT	RT	MT
<hr/>				
LD-Reading				
<u>Mean</u>	322.96	233.34	60.06	86.03 ^a
<u>SD</u>	17.32	11.96	7.01	8.32
LD-Math				
<u>Mean</u>	334.78 ^a	238.00 ^a	64.59 ^a	83.21
<u>SD</u>	9.67	10.23	5.61	6.33
Non-LD				
<u>Mean</u>	333.71 ^a	239.90 ^a	66.06 ^a	87.73 ^a
<u>SD</u>	11.08	8.18	7.50	7.41

Note. Within columns identical superscripts indicate non-significant differences. If there are no superscripts in a column, then all differences are significant.

Table 5

Descriptive Statistics for the Hick Paradigm 1-Bit

Group	Median		Intraindividual SD	
	RT	MT	RT	MT
LD-Reading				
<u>Mean</u>	337.62 ^a	249.18 ^a	74.84	91.18 ^a
<u>SD</u>	28.32	12.38	13.19	6.21
LD-Math				
<u>Mean</u>	348.00	254.28 ^a	81.50 ^a	92.09 ^a
<u>SD</u>	9.12	10.80	6.58	8.17
Non-LD				
<u>Mean</u>	341.68 ^a	247.53 ^a	80.50 ^a	84.44
<u>SD</u>	9.86	12.86	8.80	6.11

Note. Within columns identical superscripts indicate non-significant differences. If there are no superscripts in a column, then all differences are significant.

Table 6

Descriptive Statistics for the Hick Paradigm 2-Bit

Group	Median		Intraindividual SD	
	RT	MT	RT	MT
LD-Reading				
<u>Mean</u>	339.81	257.93 ^a	89.84 ^a	81.11 ^a
<u>SD</u>	40.71	9.75	10.09	7.24
LD-Math				
<u>Mean</u>	357.93 ^a	258.62 ^a	91.93 ^a	88.31
<u>SD</u>	9.80	7.98	9.53	7.43
Non-LD				
<u>Mean</u>	352.28 ^a	257.59 ^a	85.25	81.18 ^a
<u>SD</u>	14.26	6.48	10.81	6.78

Note. Within columns identical superscripts indicate non-significant differences. If there are no superscripts in a column, then all differences are significant.

Table 7

Descriptive Statistics for the Hick Paradigm 3-Bit

Group	Median		Intraindividual SD	
	RT	MT	RT	MT
LD-Reading				
<u>Mean</u>	398.09 ^a	264.25 ^a	99.37 ^a	83.91 ^a
<u>SD</u>	16.27	13.51	12.84	9.27
LD-Math				
<u>Mean</u>	397.06 ^a	267.15 ^a	94.75 ^a	83.91 ^a
<u>SD</u>	15.19	12.06	14.04	8.55
Non-LD				
<u>Mean</u>	390.34 ^a	267.59 ^a	85.65	87.22 ^a
<u>SD</u>	14.56	9.34	15.83	6.53

Note. Within columns identical superscripts indicate non-significant differences. If there are no superscripts in a column, then all differences are significant.

significance ($F(2,56)=2.73$, $p = .0707$). No significant differences in movement time occurred for the Hick 2-bit condition ($F(2,56)=0.13$, $p = .8768$) or the Hick 3-bit condition ($F(2,56)=0.86$, $p = .4256$).

Oddman Paradigm

Reaction time. Descriptive statistics and the results of the t-tests are reported in Table 8. RT on the Oddman task showed differences among groups ($F(2,56)=3.03, p = .0398$) (Huynh-Feldt correction). The non-LD group is significantly faster than both LD-Reading and LD-Math groups. The difference between LD-Reading and LD-Math groups was not significant.

Intraindividual variability. The groups differed on intraindividual variability ($F(2,56)=24.21, p < .0001$). There are significant differences between all groups. Non-LD group shows smaller intraindividual variability than either the LD-Reading or LD-Math groups.

Response errors. The groups demonstrated significant differences in the response errors on the Oddman Task ($F(2,56)=17.19, p < .0001$). The non-LD group made significantly fewer errors than both the LD-Reading and LD-Math groups.

Movement time. On the Oddman paradigm there were no significant differences among groups in movement time ($F(2,56)=0.44, p = .6425$).

Visual Search Paradigm

Reaction time. Descriptive statistics and the results of the dependent sample t-tests are reported in Table 9. The groups differed in RT on the Visual Search paradigm ($F(2,56)=95.34, p < .0001$). The non-LD group

Table 8

Descriptive Statistics for the Oddman Paradigm

Group	Median		Intraindividual SD		Response Errors
	-----		-----		
	RT	MT	RT	MT	
LD-Reading					
Mean	634.97 ^a	313.00 ^a	124.43 ^a	93.85 ^a	13 ^a
SD	18.02	10.15	10.01	8.94	05
LD-Math					
Mean	633.09 ^a	312.84 ^a	127.37 ^a	94.11 ^a	16 ^a
SD	14.07	9.75	10.84	9.54	05
Non-LD					
Mean	625.68	310.87 ^a	109.40	91.14	08
SD	13.54	10.23	10.93	8.79	03

Note. RT and MT reported in ms. Response errors reported as percentage of errors. Within columns identical superscripts indicate non-significant differences.

responded significantly faster than either the LD-Reading or the LD-Math groups.

Intraindividual variability. The groups responded with differing intraindividual variability ($F(2,56)=36.45, p < .0001$). Members of the LD-Reading group demonstrated significantly more variability than the other two groups.

Table 9

Descriptive Statistics for the Visual Search (VS) Paradigm

Group	Median		Intraindividual SD		Response Errors
	RT	MT	RT	MT	
LD-Reading					
Mean	838.46 ^a	329.87 ^a	148.78	101.65 ^a	25 ^a
SD	11.81	9.09	10.47	6.55	07
LD-Math					
Mean	836.53 ^a	329.84 ^a	142.46	99.84 ^a	25 ^a
SD	7.18	8.41	8.70	5.91	08
Non-LD					
Mean	805.53	331.84 ^a	126.06	100.23 ^a	13
SD	10.71	9.34	9.39	6.11	05

Note. RT and MT reported in ms. Response errors are reported as percentage of errors. Within columns identical superscripts indicate non-significant differences. If no there are no superscripts in a column, then all differences are significant.

Members of the non-LD group showed significantly less variability than the other groups.

Response errors. The LD-Reading and LD-Math groups showed the same response error rates. The non-LD group had significantly less errors. This difference accounted for

the significant ANOVA ($F(2,56)=64.31, p < .0001$).

Movement time. There were no significant movement time differences among groups on the visual search task ($F(2,56)=0.25, p = .7827$).

Memory Search Paradigm

Reaction time. The three groups demonstrated significantly discrepant latencies ($F(2,56)=69.76, p < .0001$). The LD-Reading group was significantly slower than either the LD-Math or the non-LD group. The LD-Math group was significantly slower than the non-LD group. Descriptive statistics and results of the dependent samples t-tests are presented in Table 10.

Intraindividual variability. There were significant differences among groups on intraindividual variability in the Memory Search paradigm ($F(2,56)=11.07, p < .0001$). Although there were no significant differences between the LD-Reading and LD-Math groups, the non-LD group responded with significantly less intraindividual variability than LD-Reading and LD-Math groups.

Response errors. MS resulted in significant differences among groups on response errors ($F(2,56)=53.66, p < .0001$). The LD-Reading group made significantly more errors than the LD-Math group or non-LD

Table 10

Descriptive Statistics for the Memory Search (MS) Paradigms

Group	Median		Intraindividual SD		Response Errors
	RT	MT	RT	MT	
LD-Reading					
Mean	796.53	347.18	127.68 ^a	98.72 ^a	21
SD	17.51	24.26	11.70	6.87	07
LD-Math					
Mean	772.34	356.28 ^a	125.93 ^a	99.14 ^a	14
SD	11.54	11.42	14.53	5.31	05
Non-LD					
Mean	755.34	356.09 ^a	114.28	99.58 ^a	10
SD	13.28	7.25	12.18	6.39	05

Note. RT and MT reported in ms. Response errors reported as percentage of errors. Within columns identical superscripts indicate non-significant differences. If there are no superscripts in a column, then all differences are significant.

group. The LD-Math groups made significantly more errors than the non-LD group.

Movement time. Significant differences appeared among groups for movement time in the memory search task ($F(2,56)=3.36$, $p = .0371$). The LD-Reading group had

significantly faster movement time than the other two groups.

Semantic Verification Task Paradigm

Untimed SVT. Group means are presented in Table 11. When administered the SVT, in an untimed condition, the LD-Reading group made significantly more errors than either the LD-Math or non-LD groups ($F(2,26)=56.49$, $p < .0001$). Three subjects (two in LD-Reading and one in LD-Math) were eliminated from analysis because they made errors greater than chance level (50%). This indicates that differences in the SVT are due to knowledge base and strategies, as well as information-processing. The SVT is not an elementary cognitive task, but rather a speeded version of a knowledge content and problem solving strategy task. These results

Table 11

Response Errors in an Untimed Version of the Semantic Verification Task (In Percentage of Errors)

	M	SD
Group		
LD-Reading	.18	.064
LD-Math	.10	.041
Non-LD	.08	.039

limit the usefulness of the other parameters from SVT. Subsequent analyses will be conducted with and without the SVT variables in order to reduce the effects of knowledge content and problem solving strategies.

Reaction time. The LD-Reading group demonstrated far longer latencies than the other two groups ($F(2,56)=94.11$, $p < .0001$). However, the LD-Math group demonstrated significantly longer latencies than the non-LD group. Descriptive statistics are presented in Table 12.

Intraindividual variability. Intraindividual variability differed markedly among groups ($F(2,56)=90.17$, $p < .0001$). Significant differences exist between LD-Math and non-LD groups and between LD-Math and LD-Reading groups. The LD-Reading group again exhibited significantly greater intraindividual variability than the other groups.

Response errors. Given that the LD-Reading group made significant numbers of errors in an untimed version of the SVT, it is not surprising that such differences became even more pronounced in the timed version ($F(2,56)=156.23$, $p < .0001$). Again, the LD-Math group made significantly more response errors than the non-LD group. The SVT clearly involves a task in which the knowledge content and problem solving strategy demands are too complex for the LD-Reading subjects. Four subjects in the LD-Reading group were

Table 12

Descriptive Statistics for the Semantic Verification Task Paradigm

Group	Median		Intraindividual SD		Response Errors
	RT	MT	RT	MT	
LD-Reading					
Mean	847.75	327.25 ^a	160.59	103.45 ^a	30
SD	16.57	11.88	17.83	9.32	09
LD-Math					
Mean	799.93	328.96 ^a	132.18	101.98 ^a	15
SD	16.10	8.24	10.76	8.99	06
Non-LD					
Mean	787.31	326.15 ^a	114.37	100.91 ^a	09
SD	22.52	7.04	12.28	9.61	03

Note. RT and MT reported in ms. Response errors reported as percentage of errors. Within columns identical superscripts indicate non-significant differences. If there are no superscripts in a column, then all differences are significant.

observed to be responding randomly, not viewing the stimuli presented. These data were eliminated from subsequent analysis.

Movement time. There were no significant differences

on the semantic verification task on movement time ($F(2,56)=0.75, p = .4774$).

Discriminant Function Analyses and Corresponding Canonical Correlations

Discriminant analysis is employed when groups of subjects are defined a priori and the purpose of the analysis is to distinguish the groups from one another based upon their profiles of test scores (Nunnally, 1978). Discriminant analysis treats variables jointly by solving for a set of weights which maximally discriminates among the groups (Lachenbruch, 1975). Once the weights are established, accuracy of placement into one of the groups based upon weights is calculated.

In order to reduce liberal bias, discriminant functions were calculated on $n-1$ observations (Lachenbruch, 1967). The discriminant weights were then used to classify the one observation left out. This was done for each subject in the sample. The misclassification rate was the proportion of observations in the group that were misclassified (Lachenbruch, 1975). The $n-1$ crossvalidation method is the most robust of the available methods of determining misclassification rates (Lachenbruch & Mickey, 1968). However, the misclassification rates should be interpreted with caution because it is likely that this estimate has a bias in a conservative direction because the groups are not independent (matched for age and intelligence).

Table 13 provides a summary of all discriminant

analyses and corresponding canonical correlations.

Chance level classification is 33%. RT (latency) from all RT tasks correctly classified 93% of the subjects. When RT from the SVT was removed from the analysis, due to SVT being far more knowledge and strategy dependent, the remaining RTs correctly classified 83% of the subjects. Combined response errors correctly classified 78%. Intraindividual variability correctly classified 69% of subjects. RT, intraindividual variability, and response errors from all RT tasks, save SVT, combined correctly classify 89% of the subjects. This last result indicates that the knowledge and strategy reduced tasks effectively discriminate among LD-Reading, LD-Math, and non-LD groups.

A canonical correlation is the maximized correlation between two sets of variables. Canonical correlations were derived by coding dummy variables for the nominal groups variable. Canonical correlations were calculated for these dummy variables and the desired RT variables (Cohen & Cohen, 1975). These correlations give information about the total variance in the RT variables accounted for by the groups. They are reported in Table 13. All combination of variables examined, save the combination of MT variables, correctly classify subjects at a level greater than chance.

Table 13

Percentages of Subjects Correctly Classified by RT Variables
and Corresponding Canonical Correlations

Variables	% Correctly Classified	Canonical Correlations
OE VE ME SE	78	85
V M	79	79
H0 H1 H2 H3 O V M	83	72
H0SD H1SD H2SD H3SD	69	61
OSD VSD MSD		
H0 H1 H2 H3 O V M S	93	87
H1 H3 O V M H1SD H3SD	89	83
OSD VSD MSD OE VE ME		
S SSD SE	78	71
O OSD OE	59	51
M MSD ME	68	69
V VSD VE	70	63
MH0 MH1 MH2 MH3 MO MV	38	33
MM MS		

CHAPTER 4 SUMMARY AND DISCUSSION

The present study was undertaken to determine the extent to which ECTs, with reduced knowledge content and problem solving strategies, discriminate among reading disabled children, mathematics disabled children, and children without identified learning disabilities. Four variables derived from the RT tasks were median RT, intraindividual variability, MT, and response errors.

If RT is to be useful in the study of hardwired substrates of learning disabilities, it necessary to determine whether RT is measuring a general, enduring trait within individuals. Internal consistency of the RT tasks ranged from .74 to .96. These reliability figures are in the range of many psychometric tests used to make decisions about individuals. There was also no evidence for a speed-accuracy trade-off on RT tasks. Order effects did not interact with groups. This indicates that order effects, where they existed, were ostensibly the same for each of the three groups. Thus, the effects were not significant in this study. The criticisms aimed at RT as a method of investigating cognitive processes did not appear to be supported by the data. The data do not indicate that

methodological procedures were a confounding factor in this study of individual differences.

Before discussing the implications of the general results, the results of each separate hypothesis will be reviewed. The data support all hypotheses put forth in Chapter 1, except one. Median RT, intraindividual variability, and response errors when used in combination correctly classified subjects into LD-Reading, LD-Math, and Non-LD groups at far greater than chance levels. In fact, most of the variance among groups can be accounted for by RT variables.

Hypothesis one was supported. The LD-Reading group demonstrated greater mean latency and intraindividual variability than LD-Math or non-LD groups on the SVT. A major difficulty is that the LD-Reading group made 18% errors on the untimed SVT. Thus, it is not surprising that in a timed condition the LD-Reading group was slower and less consistent than the other two groups. A case can be made that the SVT is too complex a task to be considered an ECT for LD-Reading groups.

Hypothesis two was partially supported. Both LD-Reading and LD-Math groups showed greater mean latency and intraindividual variability than the non-LD group on the Oddman paradigm, replicating the study by Michelson (1990). Contrary to the hypotheses, the LD-Reading group were significantly faster on the Hick 0, 1, and 2 bit conditions

than the other groups. Also contrary to the hypotheses are the results of the Hick 3-bit condition. There were no significant differences on the Hick 3-bit task. The LD-Reading group evinced smaller intraindividual variability than the other groups on the Hick 0-bit and 1-bit conditions. These results fail to replicate Michelson's study (1990). On the Hick 2-bit and 3-bit conditions, differences existed in the predicted direction.

Hypothesis three was supported. The LD-Reading and LD-Math groups had greater mean latencies and intraindividual variability than the non-LD group on MS and VS tasks. This implicates the process of short-term memory as a variable which differentiates LD groups from the non-LD group.

Hypothesis four was supported. Response errors on the SVT were significantly greater in the LD-Reading group than LD-Math and non-LD groups. As mentioned before, SVT may be too complex to be considered an ECT, because the LD-Reading group had difficulty performing the task in an untimed condition. Hence, the complexity of the SVT may have overloaded the capacity of STM in the LD-Reading group. Also, the LD-Reading group may not have had the prerequisite reading skills and automatized knowledge of prepositions assumed in the SVT.

Hypothesis five was supported. Response errors on the Oddman, MS and VS tasks were significantly greater for LD-Reading and LD-Math groups than non-LD groups. These tasks

were much simpler than the SVT. Although response error rates were high in the speeded condition, there was no evidence that the knowledge and skills demanded by these tasks were too complex for any group. Thus, these tasks can be considered ECTs. The differences between non-LD and LD groups are likely due to LD children making decisions based on too little information, rather than an overload of STM capacity.

Hypothesis six was supported. There were no significant differences among groups on the movement time variables. This is not surprising considering that MT accounts for peripheral sources of variance, rather than central processes implicated in learning disabilities.

One of the most interesting and counterintuitive findings is that the LD-Reading group was faster than the LD-Math and non-LD groups on the Hick 0, 1, and 2 bit tasks. On the Hick 0 bit condition, the LD-Reading group was consistently faster than the other two groups throughout the distribution. However, on the 1 and 2 bit conditions it was clear that there was a subset of five subjects in the LD-Reading group who were significantly faster than any other subjects. This subset of the LD-Reading group was not significantly faster on any of the other tasks. Perhaps this subset represents a generalizable subtype of learning disabilities which has not been identified. The use of RT may help to identify finer grained subtypes of learning

disabilities than were identified in this study. However, this subset did not differ significantly from other LD-Reading subjects on any of the psychometric variables. Of course, sampling error is a plausible and perhaps even a probable cause of these anomalous findings.

Nonetheless, these unexpected findings are a major reason that the discriminant function analyses resulted in such a low error rate. That LD subjects were slower, more variable, and made more errors on RT tasks than their non-LD peers was clear. The differences between LD-Reading and LD-Math groups was not as clear on the Oddman, MS, and VS. However, the fact that the LD-Reading group was faster than the LD-Math group (due to an extremely fast subset of the group) helped to discriminate between the groups. The possibility that sampling error helped to cause the extremely high accuracy of the classification of subjects into groups means that these results should be interpreted with caution. The need for replication of these results is apparent.

On the Oddman, the LD-Reading and LD-Math groups were equivalent on RT and RTsd; however, the LD-Math group made significantly more errors. It may be possible that discrimination of non-symbolic data demands the same processes necessary for mathematics. The evidence is not strong for this hypothesis, however, it does demand further investigation.

Response errors occur at a rate well above that observed in other studies for all groups. Mean response error rates reached 30% (LD-Reading group on SVT). Also interesting was a lack of evidence supporting speed-accuracy trade-off in the LD samples, as predicted by Spring (1976). This would indicate that LD subjects make errors for reasons other than the hypothesis that subjects respond before information processing was complete. Perhaps LD children simply make decisions before completely processing information, as reported in a mild mentally retarded sample (Nettlebeck & Brewer, 1981).

Although it is impressive that the battery of RT latencies correctly classified subjects with 83% accuracy, it should be remembered that groups were selected primarily using psychometric tests and teacher reports. Perhaps the use of RT provides some support for assessment methods used to identify LD children in the schools. These results also support one of the assumptions common in the definitions of learning disabilities, that information-processing deficiencies are a hallmark of the disorder. It is clear that knowledge content and problem solving strategies cannot account for all of the differences between LD and non-LD children.

Although a low intelligence group was not included in the sample and it is difficult to compare across studies, the differences between the non-LD and LD groups in this

study are similar to differences between low intelligence and average intelligence subjects in previous studies (Fletcher & Morris, 1986; Harris & Flear, 1974). Perhaps this provides evidence that differences between LD and low intelligence individuals are ones of degree rather than kind. The strongest form of this hypothesis is that LD and low intelligence individuals do not differ at all in cognitive processes. Differences between the two groups may be primarily a social consideration, because, for most parents, the diagnosis of learning disabilities is more desirable than that of low intelligence. Certainly, these social consideration exist in the placement of handicapped children in the schools. Although social considerations are important for the schools, they make the definition and study of the nature of learning disabilities a difficult and often inexact science. Future studies should consider the relationship between learning disabilities and low intelligence subjects closely.

Using a sample of LD subjects which was subtyped into reading disabled and mathematics disabled groups was a new method in the study of RT and LD. Eliminating children from the sample who had reported behavior problems and were prescribed psychotropic medication, as well as including only children with a 15 point discrepancy between Verbal and Performance IQ on the WISC--R reduced heterogeneity common in many samples of LD subjects. The intent was to include

subjects with processing deficits, and eliminate those with attention deficit disorder, hyperactivity, or emotional problems. Even the samples used in this study may not reduce the heterogeneity inherent in the class of children labelled learning disabled. Subtyping the LD population into even finer groups, based on information-processing deficits, may be possible and desirable for further research and practice.

The results of this study provide strong evidence that LD children are different in speed of processing, intraindividual variability, and response errors on tasks demanding the most fundamental, knowledge-reduced, and strategy-reduced processes. Given that there are no systematic order effects or order by group interaction and that there was not a speed-accuracy trade-off these differences most likely have a biological component. Some possible biological causes are speed of signal propagation through neurons is slower in LD populations; more frequent errors are made in the movement of information across synapses; or information is transmitted through an inefficient, circuitous route throughout the cortex resulting in slower and more error-prone information-processing in LD subjects. Investigations of biological bases of cognitive deficits likely will necessitate the use of instruments to study brain physiology.

The present study is exploratory in nature. Perhaps

more methodological and theoretical questions were raised than answered. There are several factors which may result in LD subjects performing differently than non-LD subjects, but were not investigated in this study: boredom with the long battery; attention deficits; deficiencies associated primarily with the visual channel, as opposed to a central processing or auditory-processing deficit; and effects of hyperactivity (often associated with learning disabilities) on RT. However, the use of a battery of knowledge and strategy-reduced RT tasks resulted in the startling accuracy of correct classification into non-LD, LD-Reading, and LD-Math groups. These results signal that further research with RT has potential to answer important theoretical questions concerning information processing, mental ability, and learning disabilities.

There are additional limitations to this study. Given that group membership accounts for a great deal of the variance in RT variables, the possibility of capitalization on nonrandom error (bias) in the sample selection exists. Given that limitation, a replication of these results is necessary. Also, the battery of RT tasks needs to be shortened significantly. Several subjects complained of boredom after the 432 trial of the battery. All tasks used in this study involved visually presented information. The use of RT involving other sensory input channels, especially auditory, could provide insight into the source of

processing deficiencies in LD subjects. Using a more fine grained subtyping of the LD population may help to identify deficient processes. Comparing differences between LD and low intelligence subjects may supply data in the investigations of the nature of information processing and cognition.

Future research in the investigation of learning disabilities and ECTs has several possible directions. In order to investigate the biological bases of processing deficiencies in LD children, physiological tests, such as positron emission tomography, nerve conduction velocity, and neuropsychological assessment instruments may prove useful. Positron emission tomography may provide information about the efficiency of the working brain while solving academic problems. Nerve conduction velocity gives a measure of the speed of propagation of an action potential through neurons. Neuropsychological assessment can investigate gross brain functioning and isolate brain lesions through behavioral means. These instruments may provide useful information in the investigations of the fundamental nature of learning disabilities.

APPENDIX

UNTIMED SEMANTIC VERIFICATION ITEMS

T	F	B FIRST	CBA
T	F	B BETWEEN A & C	CAB
T	F	A NOT AFTER C	ACB
T	F	A LAST	CBA
T	F	B NOT BEFORE A & C	ABC
T	F	C FIRST	CBA
T	F	B NOT BEFORE C	ACB
T	F	C AFTER A & B	CAB
T	F	B AFTER A	ACB
T	F	A NOT BEFORE B	ABC
T	F	A BEFORE B	CBA
T	F	C BETWEEN A & B	ACB
T	F	C BEFORE A & B	CBA
T	F	B BEFORE A	ACB
T	F	C NOT FIRST	ABC

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BIOGRAPHICAL SKETCH


Steven R. Shaw received his B.S. in psychology from the University of Florida in May of 1985. He earned his M.Ed. and Ed.S. in school psychology from the University of Florida in August of 1988. He has recently wed Ms. Joyce M. Narvades. They make their home in Normal, Illinois.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.



James J. Algina, Chair
Professor of Foundations of
Education

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.




John H. Kranzler
Assistant Professor of
Foundations of Education

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.



Craig L. Frisby
Assistant Professor of
Foundations of Education

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.



Walter Cunningham
Professor of Psychology

This dissertation was submitted to the Graduate Faculty of the College of Education and to the Graduate School and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

December 1991



Chairman, Foundations of
Education



Dean, College of Education

Dean, Graduate School